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Response of a $LaBr_3$(Ce) Detector to 2-11 MeV Gamma Rays

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Abstract*–The development of lanthanum halide scintillation detectors has great potential application in field-portable prompt-gamma neutron activation analysis systems. Because the low-energy response of these detectors has already been well-characterized [1[-[2], we have measured their response to higher energy gamma rays in the region between 2 and 11 MeV. We have measured the response of a 2-inch (5.08 cm) by 2-inch long $LaBr_3$(Ce) detector to high energy gamma rays produced by neutron interactions on chlorine, hydrogen, iron, nitrogen, phosphorous, and sulfur. The response of the LaBr3(Ce) detector is compared to that of HPGe and NaI(Tl) detectors.

I. Introduction

Prompt gamma-ray neutron-activation analysis (PGNAA) systems, like Idaho National Laboratory's Portable Isotopic Neutron Spectroscopy System (PINS) [1], excite and measure multi-MeV gamma rays. As an example, for explosive detection, PGNAA systems usually determine the presence of nitrogen within a suspect object from the 10.8 MeV nitrogen capture gamma ray. Scintillation detectors are attractive for high-energy gamma-ray measurements by their high detection efficiency but low energy resolution, relative to germanium detectors. The recently developed lanthanum halide scintillators are of particular interest because of their remarkably high energy resolution compared to traditional scintillator materials such as NaI(Tl) and BGO.

The low energy response of $LaBr_3$(Ce) has already been well-characterized [2]-[3]. We have measured the response of a 2-inch by 2-inch $LaBr_3$(Ce) detector to multi-MeV gamma rays produced through neutron interactions on chlorine, hydrogen, iron, nitrogen, phosphorous, and sulfur. These elements are of particular interest in identifying chemical warfare materiel (CWM) and explosives. The elemental composition of various CWM and explosives is shown in Table I. The energies of gamma rays of interest from some of these elements are shown in Table II. As can be seen in the table, the gamma rays range in energy from 1.3 to 10.8 MeV. We also compare response of the $LaBr_3$(Ce) detector to a 5 x 5-in NaI(Tl) detector as well as a 45% relative efficiency HPGe detector.

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TABLE I
ELEMENTAL COMPOSITIONS IN WEIGHT % OF CWM AND EXPLOSIVES [4]-[5]

	Sarin (GB)	**Soman** (GD)	**Tabun** (GA)	**VX**	**Mustard** (H)	**Lewisite** (L)
Hydrogen	7.1	8.8	6.8	9.7	5.0	1.0
Carbon	34.3	46.2	37.0	49.4	30.2	11.4
Oxygen	22.9	17.6	19.8	12.0	-	-
Nitrogen	-	17.3	-	5.2	-	-
Fluorine	13.6	10.4	-	-	-	-
Phosphorus	22.1	17.0	19.1	11.6	-	-
Sulfur	-	-	-	12.0	20.1	-
Chlorine	-	-	-	-	44.7	51.3
Arsenic	-	-	-	-	-	36.1

	Comp. B	**HMX**	**PETN**	**RDX**	**TNT**
Hydrogen	2.5	2.7	2.5	2.7	2.2
Carbon	24.5	16.2	19.0	16.2	37.0
Oxygen	42.8	43.2	60.8	43.2	42.3
Nitrogen	30.4	37.8	17.7	37.8	18.5

TABLE II
GAMMA RAY ENERGIES (keV)

H	**N**	**P**	**S**	**Cl**	**Fe**
2223.25	5269.16	1266.15	2230.3	1164.86	7631.13
	10829.1	2233.7	5420.6	1951.14	7645.54
				1959.35	
				6110.8	

II. Experimental Method

The experimental arrangement is shown in Fig 1. The same geometry was used for each detector type. A 5- microgram ^{252}Cf neutron source was placed in a 4-inch by 4-inch polythethylene moderator block, which was shielded from view by the detector by 4 inches of tungsten. The detector was also placed inside a bismuth collimator of 1/2-inch thickness. The test items consisted of steel cylinders filled with red phosphorous, bleach, potassium chloride, sulfur, water, and melamine and glucose. Spectra were measured for each test item for 3,000 live seconds.

An Ortec Digidart was used to process the signals from the HPGe detector and an Ortec Digibase for the scintillator-based detectors. The HPGe spectra comprised 8,192 channels whereas the $LaBr_3(Ce)$ spectra comprised 1,024 channels. The energy ranges of the spectra were approximately 0.1-12 MeV for both sets of electronics.

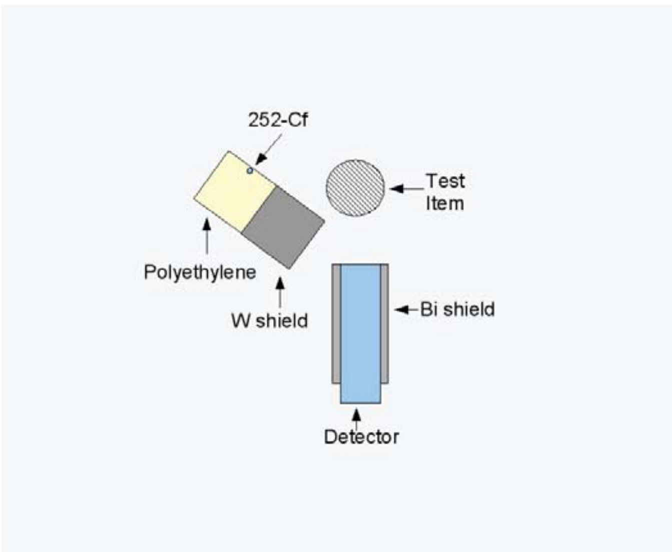

Fig. 1. Experimental Arrangement. It should be noted that the bismuth collimator was not used during the 5x5 NaI(Tl) detector measurements

III. Results

The manufacturer of the $LaBr_3(Ce)$ detector warranted an energy resolution of 2.8% or 18.5 keV for the ^{137}Cs 662 keV gamma ray, and our measurements of its energy resolution confirmed this value. Additional measurements were made using ^{60}Co and ^{152}Eu to provide the resolution as a function of energy for the region between 244 and 1408 keV. Fig. 1 below shows the results of these measurements, as well as the resolution obtained from neutron interactions on various materials. As can be seen in the Fig., the energy resolution falls to less than 1% at approximately 6 MeV. The resolution also follows the expected $E^{-1/2}$ dependence as shown by the least-squares fit through the data points.

Overlays of spectra from each of the detector types are shown in Figs 3-8. As can be seen in the Figs. the $LaBr_3(Ce)$ detector has excellent energy resolution in all energy regions of the spectra when compared with NaI. As expected, the resolution is approximately a factor of ten worse than that of the HPGe detector.

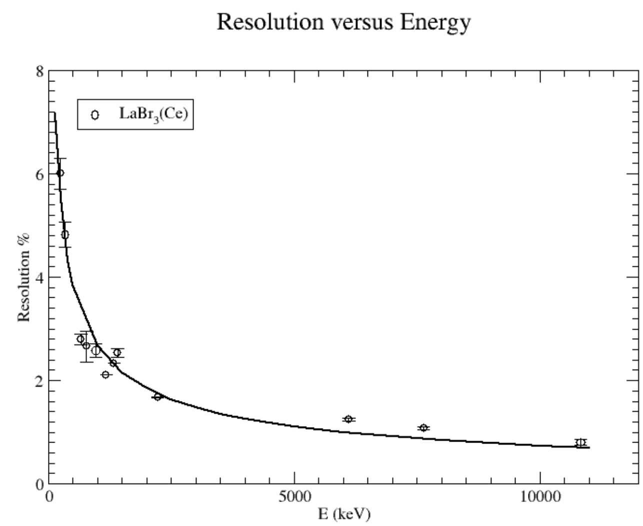

Fig. 2 Energy resolution of $LaBr_3(Ce)$ detector

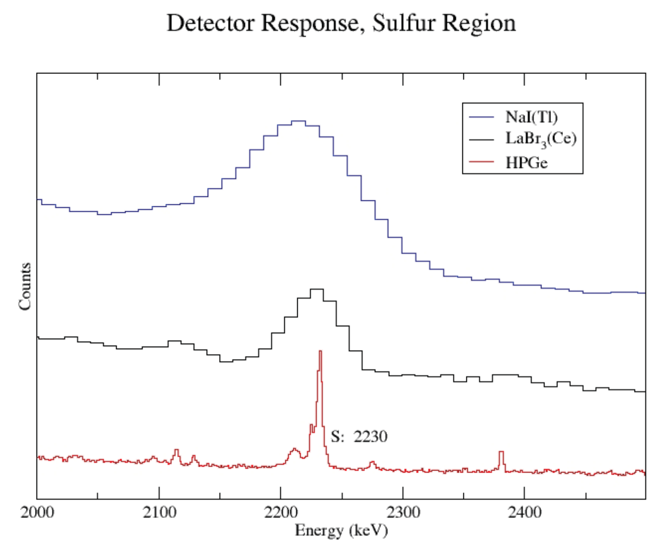

Fig. 3. Response of $LaBr_3(Ce)$and NaI detector in the S region

Fig. 3 shows the detector responses in the sulfur region of the spectra. The HPGe detector allows resolution of the sulfur (2230 keV) and hydrogen (2223 keV) gamma rays. Neither the NaI nor the $LaBr_3(Ce)$ detectors are able to resolve the two peaks. The energy resolution of the $LaBr_3(Ce)$ detector in this energy region is approximately 39 keV.

The phosphorous region of the spectra is shown in Fig. 4. In the Fig. there are a few peaks near the strong 1266 keV phosphorous inelastic scattering peak. The strong peak is easiliy distinguishable in all three detectors. The energy resolution of the $LaBr_3(Ce)$ detector is approximately 30 keV in this region, making distinguishing the 1260 keV iron peak adjacent to the phosphorous peak difficult.

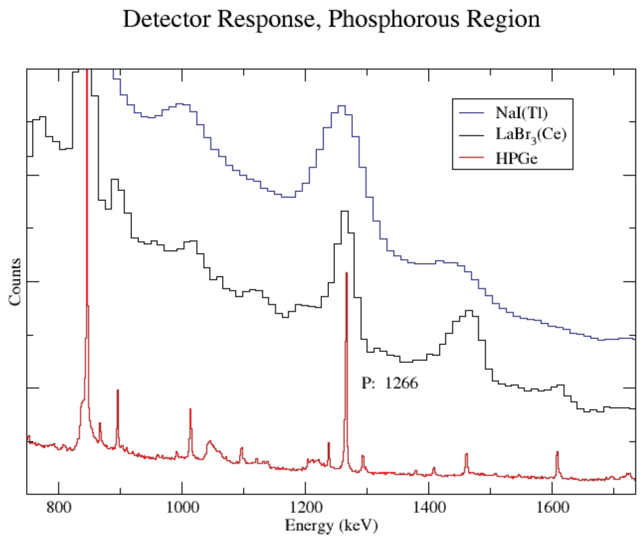

Fig. 4. Response of $LaBr_3(Ce)$, NaI(Tl), and HPGe detectors in the P region

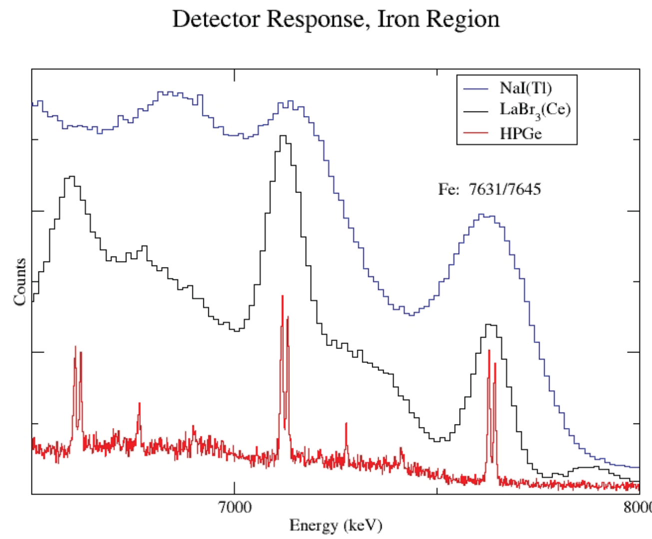

Fig. 6. Response of $LaBr_3(Ce)$, NaI(Tl), and HPGe detectors in the Fe region

Chlorine and hydrogen peaks are evident in the spectra shown in Fig. 5. The chlorine doublet (1951 and 1959 keV) is not resolved in the scintillator spectra, but the unresolved peaks are easily distinguished from the 2223 keV hydrogen peak.

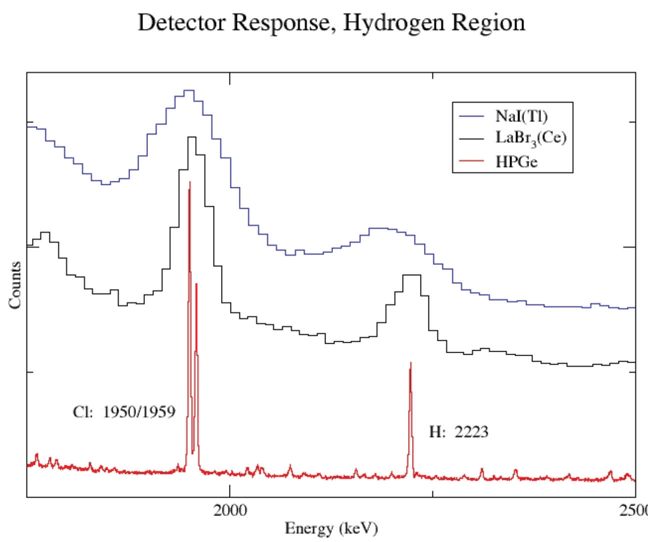

Fig. 5. Response of $LaBr_3(Ce)$, NaI(Tl), and HPGe detectors in H region

The iron peaks at 7631 and 7645 keV are shown in Fig. 6. Again, the scintillator-based detectors cannot resolve the doublet. The energy resolution of the $LaBr_3(Ce)$ detector is approximately 68 keV in this region.

The highest-energy region of the spectrum that we examine, namely the region near the 10.8 MeV nitrogen peaks is shown in Fig. 7. The nitrogen 10.8 MeV gamma-ray peak is clearly resolved from the first and second escape peaks in the $LaBr_3(Ce)$ spectrum

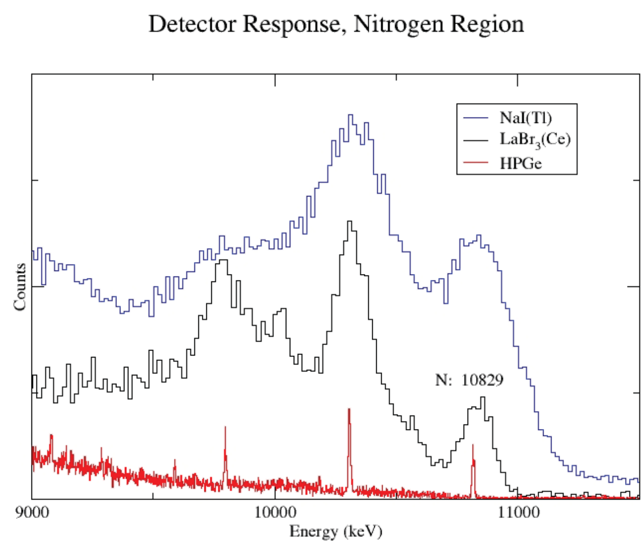

Fig. 7. Response of $LaBr_3(Ce)$, NaI(Tl), and HPGe detectors in N region

The $LaBr_3(Ce)$ detector does have some intrinsic activity, due to the presence of ^{138}La. This nuclide emits 789-keV and 1436-keV gamma rays in its decay. These gamma rays are evident in the background spectrum, but are not a significant interference in this active-interrogation application. Fig. 8 shows a region of the spectrum with and without the ^{252}Cf source present. As can be seen in the Fig., once the source is present the spectrum is dominated by gamma rays produced through neutron interactions on the shielding and detector stand materials such as Fe and Al.

The count rate in the detector without the source present was measured both before and after a 90-minute irradiation and was found to increase from approximately 240 Bq to 300 Bq. This measurement was performed with all shielding and detector stand present.

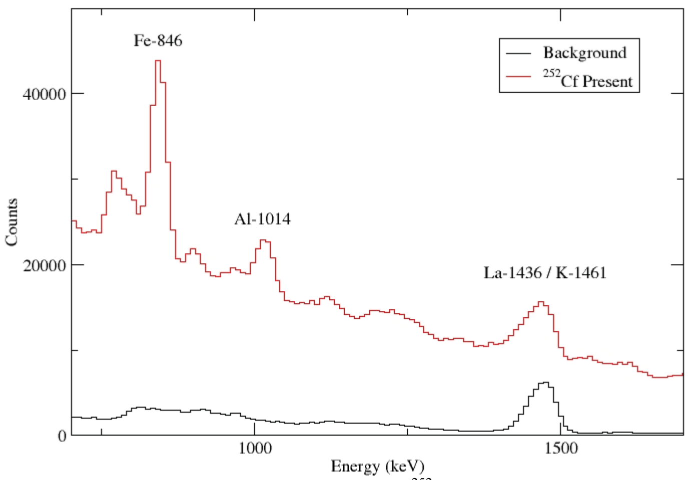

Fig. 8 Response of $LaBr_3(Ce)$ with and without ^{252}Cf.

IV. Conclusions

The $LaBr_3(Ce)$ scintillator detector has definite promise in field-portable PGNAA systems. Although the energy resolution of the detector is inadequate to resolve closely spaced peaks, it is certainly adequate to identify some of the strong gamma rays of interest in CWM and explosives. The energy resolution, combined with its high efficiency and lack of a need for liquid-nitrogen cooling, make it a very good prospect for this application.

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